The Antarctic Ice Borehole Probe

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Abstract—The Antarctic Ice Borehole Probe mission is a glaciological investigation, scheduled for November 2000-January 2001, that will acquire visible-light images and video in a hot-water drilled hole in the West Antarctic ice sheet. The objectives of the probe are to observe ice-bed interactions with a downward looking camera, and ice inclusions and structure, including hypothesized ice accretion, with a side-looking camera. The Probe mission also serves as a stepping-stone in the development of technology to acquire data in extreme ice and liquid environments. The information and experience will aid projects involving exploration in ice/liquid environments, including missions to Lake Vostok in Antarctica, Mars Polar Caps and Europa, Jupiter's moon. This focus of this paper is to describe the design and use of the probe.

TABLE OF CONTENTS

1. INTRODUCTION

The basal regime of ice sheets and glaciers is of increasing interest. This interest stems from a new appreciation of the role of the rock-ice-water system processes of the subglacial in the dynamics of ice sheets [1], the response of (even quite large) ice masses to climate change, and the creation of habitat for a community of chemotrophic microbes thought to contribute to local biogeochemical weathering [2]. Observational work [3] in the basal regime is challenging: the pressures are high, access is difficult, removal of ice samples is cumbersome because the warm ice is not competent, and the process of drilling into the ice alters the environment of interest. In the study for which the Ice Borehole Probe has been designed we address these issues through development of an in situ deployment strategy which acquires a video record of the ice sheet adjacent to a hot-water drilled hole. The drilling process has not significantly affected this ice, either chemically or physically, and considerable information about it can be derived from other optical probes, e.g., Raman and fluorescent spectrometers, to be developed in future. Additionally, the probe will collect the first visual data set on the interaction of an ice sheet with its bed, in this case a mix of wet and frozen material, probably sedimentary in origin. This unique inspection of a fundamental geological process is of great interest. Clearly the system-level requirements on a subglacial probe are significant in all areas, including general robustness, high data rates, high pressure, lighting, tether management, and the like. This is the first time that all these matters have been considered in this sort of probe.

To address some of these issues, the Antarctic Ice Borehole Camera mission is to be conducted in the 2000–2001 Antarctic field season (November 2000–January 2001), in collaboration with ice stream basal process studies conducted by scientists from the California Institute of Technology. The system designed and built for the mission is simply called the Probe hereafter; its design and implementation was funded by NASA Earth Sciences Enterprise, and its deployment was funded by the Office of Polar Program of the National Science Foundation. The mission study has scientific objectives of obtaining data on ice stream-bed interactions, on the mineralogical material in the basal ice, and on ice structure in the lower ice sheet, with emphasis on observations of hypothesized accreted ice in areas of the ice streams known as "sticky spots." These scientific objectives have resulted in observational objectives to acquire video images with a downward-looking camera and sequential digital still images with a side-looking camera, with the attendant requirement to provide illumination for both geometries.

The development, test and deployment of the Probe to meet these requirements also serves to develop the technology for acquisition of optical data in remote, high-pressure, liquid and ice environments. The experience and information will be of value in future terrestrial and planetary projects, including missions to sub-glacial lakes such as Lake Vostok in Antarctica, the Mars Polar Caps and to Europa, a Jovian moon thought to have a deep ocean beneath an ice crust.

The task of the Antarctic Ice Borehole Camera Mission is to develop and deploy an instrumented ice/water Probe for depths up to 1.4 km in deep ice wells to obtain image data both down the hole and laterally into the ice. A key challenge for the Probe is in the extreme operating pressure, the consequence of being at a depth of 1.4 km of fresh water, in which the structure, equipment, and optical elements must function. While assembly is performed at sea level and room temperature, the environmental pressure of the Probe ranges to over 130 atm at depth in the ice well, and the Probe must tolerate temperatures near –40 °C.

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The narrow diameter of the probe also creates challenges, requiring miniaturization of instruments and complex lighting geometry. In addition there was a time constraint, with quick feasibility testing set for early February, system testing for August, and the mission itself in November; and the budget for the development was quite modest.

Deep boreholes will be drilled through the Antarctic ice sheet using a proven hot-water jet technology developed by Caltech [1]. The boreholes will be kept large enough (~17 cm diam.) by reaming for the passage and safe return of the Probe.

2. Probe Design

This section describes the Probe design and discusses some of the system components. The Probe was designed with the requirements and constraints as listed below.

2.1 Requirements and Constraints

Time:	20 hours drilling, 4–6 hours working time due to refreezing.
Bandwidth:	At least 1Mbit/s for adequate real-time feedback
Size:	12-cm outer diameter.
Temp:	0 °C working; –40 °C transit
Schedule:	9 months, including testing
Redundancy:	2 complete Probe/reel systems
Sensors:	Down and side looking cameras, with light sources
Data Storage:	Digital Video
Live Real-Time:	In situ video display.
Reel:	Single tether system

The above requirements and constraints dictated design decisions implemented to produce a highly functional, reliable, robust probe system.

The project team used off-the-shelf parts where possible in order to reduce cost, schedule, engineering development, and workforce. Figure 1 shows a sketch of the stainless steel Probe housing and the internal components, including the camera systems

2.2 Probe hull

This portion of the Probe contains the cameras and associated electronics. Two CCD cameras are used. A high-quality digital camera (side looking) and a high-resolution video camera (down looking) acquire the images. We use halogen bulbs to provide illumination, with one bulb for the side looking camera and two bulbs for the down-looking camera. NTSC Video-to-Analog fiber optic converters send images through the tether in real time to the surface Ground Station. For power, high voltage DC is sent down the tether cable and a 300V DC to 12V DC converter provides ‘clean’ power for the cameras and data transmission functions. The probe housing is used to conduct and dissipate heat from the electronics and power conversion units.

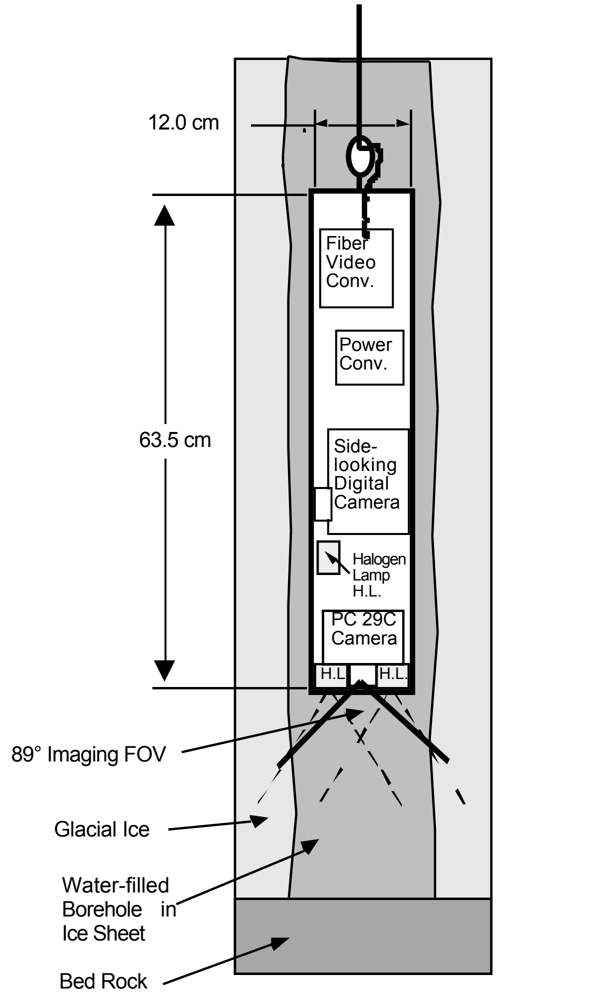

Fig. 1. Schematic of Ice Borehole Camera Probe deployed in ice well.

2.3 Deployment System.

Figure 2 shows the deployment system that lowers the probe through the ice borehole. The spool is about 0.9 m in diameter, holding 1500 m of tether.

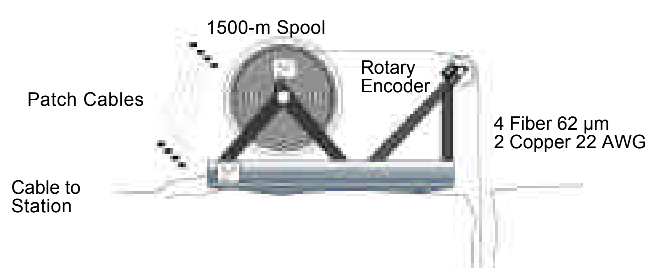

Fig. 2. Reel System.

The tether-support system, shown in Figure 2, is a direct copy of reel systems utilized in past years by the Caltech group, with the only significant difference being the tether itself. The tether is a single cable system that provides data, power, structure, waterproofing and support (strength) members. The data are transferred along four optical fiber lines and power is transmitted along two 18 AWG wires. The entire unit, the cable, spool, motors and sled, weigh approximately 180 kg. The main spool is rotated with a three-phase AC motor giving a payout rate of about 1 m/s.

2.4 Ground Station.

The Ground Station is shown in Figure 3. It contains the video display, control computer and recording devices.

The display is a high-resolution video monitor that displays either of the video feeds sent from the probe. Two digital tape recorders are used to store the images as they are received. A Sony L620 PC computer is used after images are acquired to digitally manipulate the images and analyze their contents.

2.5 Assembled Subsystems.

Figures 4 and 5 are pictures of the actual units that were sent to Antarctica. Figure 4 shows the internal components held together by a frame containing two threaded rods that hold a series of plates. The plates support the cameras, lights and other components of the system. The pressure hull is shown in Figure 5 and contains the two quartz windows on the side (one for the camera and one for the halogen bulb) and the quartz window on the bottom for the two down looking lights and camera. Figure 6 is a diagram detailing the components and interconnections of the separate systems.

3. Probe Deployment

Although borehole picture systems have been applied successfully to problems in well-drilling, mineral exploration, and relatively thin valley glaciers [2] they have not been used previously in the study of ice sheets.

3.1 Test Deployment

In order to field test the end-to-end system, a deployment was conducted in Crater Lake, Oregon in August 2000. Crater Lake was selected as a test site for the Probe because it is the coldest, deepest lake that is logistically close to southern California. The test covered the integrity of the Probe and all operations; the actual test involved the deploying the Probe into the deepest portion of Crater Lake and imaging that portion of the lake bottom (~570 m). The Probe was lowered and raised from a stationary boat via the tether system described above. This operation required the use of the National Parks Service research vessel "Neuston," and the Probe team received excellent support from the National Park Service staff. Figure 7 shows one of the images gathered during one of the preliminary deployments at the lake's fumaroles. The bars leading in to the picture are half-meter long metal rods with flags to visualize distances in front of the probe.

3.2 Field Deployment.

The final field deployment of the Probe is at Ice Stream C in Antarctica [5]. Its location is approximately 825 km from the South Pole and the surface temperature during the study will range from about –23 °C to about –15 °C.

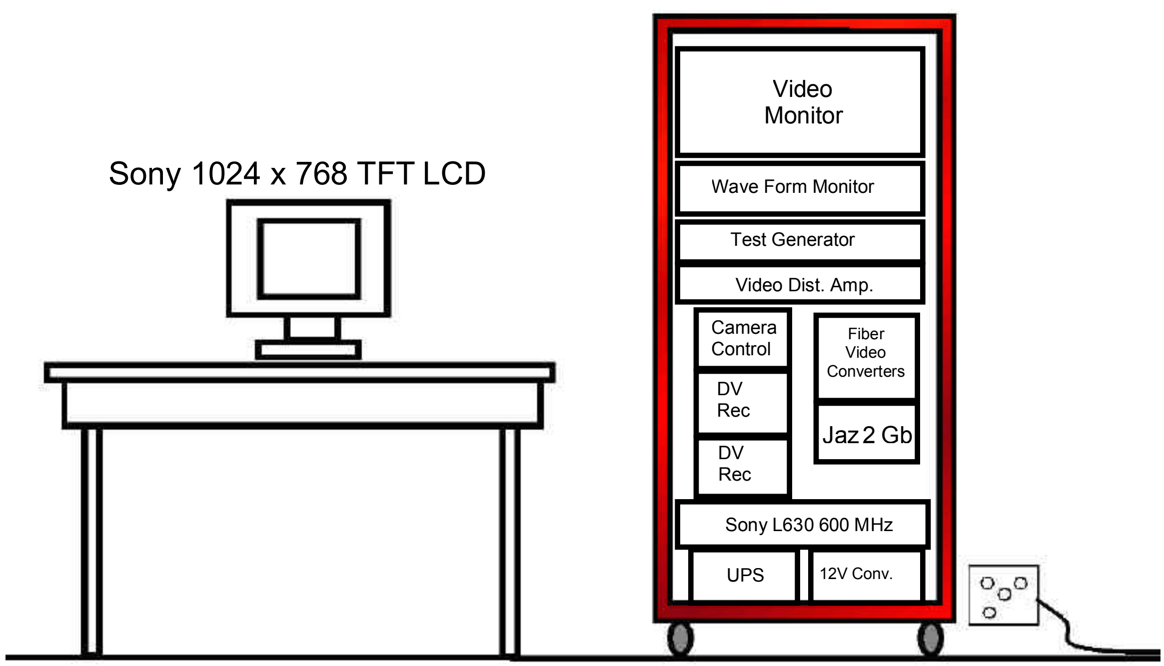

Fig. 3. Probe Ground Station.

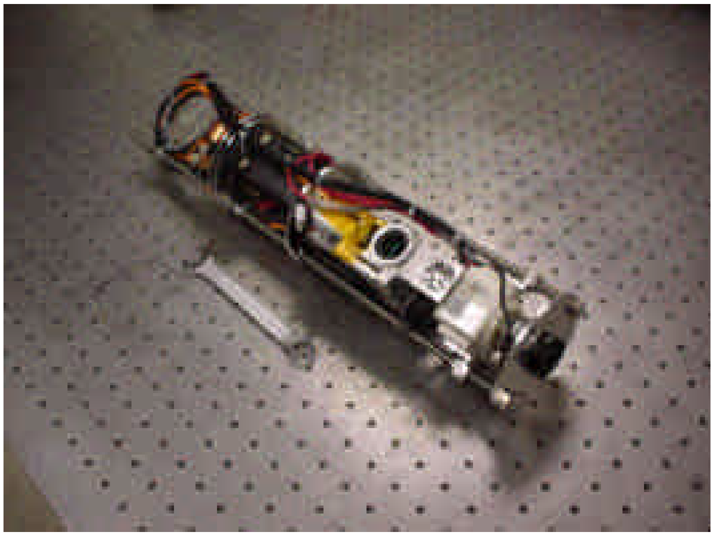

Fig. 4. Probe Instrumentation.

Fig. 5. Probe Pressure Hull, Showing Windows.

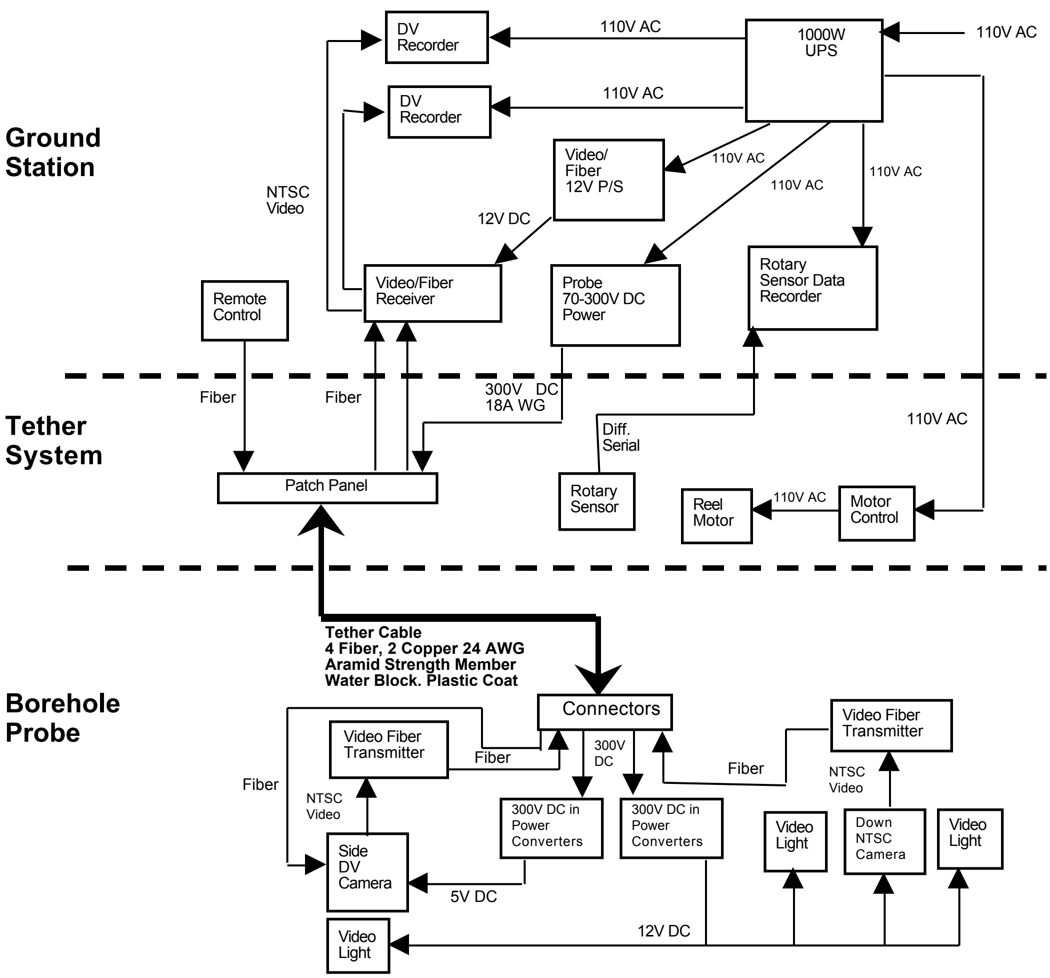

Fig. 6. Probe System Diagram.

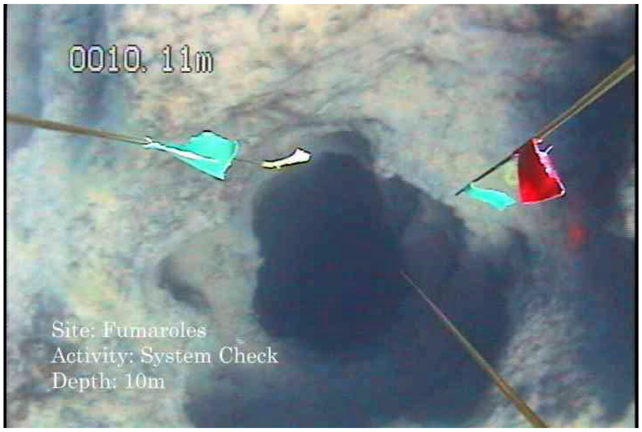

Fig. 7. Crater Lake Fumaroles.

The Caltech Antarctic program will drill a number of boreholes across Ice Stream C as part of their study of basal processes. Our approach is to deploy the Probe into some of these boreholes and record images of:

1) Ice sheet—bed interactions as the ice moves, through sliding and deforming;
2) Lower ice sheet structure with emphasis on identification of layers of ice thought to be accreted on the bottom of the ice sheet in slower moving areas called "sticky spots";
3) Observations of air bubbles and mineralogical inclusions in the ice; and
4) Observations of isochronal layers, which are ice formed from snow that fell after major volcanic eruptions.

In addition to the Probe, several other instruments will be deployed including: thermistor strings, pressure transducers, conductivity probes, ice motion sensors, etc. Ice cores and sub glacial till samples will be collected for analysis in the laboratory. A total of 16 boreholes are planned during the 2000–2001 program. Figures 8 and 9 show previous field deployments; this year's will be similar.

The Probe system diagram shown in Figure 6 gives an overview of the three main segments of the system being deployed in 2000–2001. The power for the down-hole probe comes from a 300 VDC source at the surface and delivered through the tether. In the probe it is converted in 5 and 12 V DC bus voltages. Electrical video signal data from the cameras are converted into optical streams and each is sent up a separate optical fiber to the surface station. The downward looking camera has only a power-on, automatic operation mode. The side looking camera records internally up to 2 hours of digital video, as well as sending out a real-time, analog video stream. The side looking camera has control command function via an optical fiber command line from the surface; hence the scientist/operator can zoom and focus onto interesting objects seen in the real-time stream.

The surface ground station provides power (110 V AC) for the computer equipment that records and displays image and engineering data and issues commands to the probe. The analog image data streams from the cameras are recorded onto digital format recorders to preserve data quality for numerous replays, and the control station computer decodes the probe depth information from the cable reel rotations. All the data are time tagged to enable detailed correlations post-facto. To assist the operator to locate unique features, the real-time video display has sub-windows for depth and time. The highest quality digital images, recorded on DV tape within the side-looking camera, are removed from the probe and camera housing after the probe is returned to the surface station. Time tagging provides a direct correlation between these taped images and the analog real-time recorded images.

4. Conclusions

This research has the objective of gaining knowledge about the Antarctic ice sheet processes as well as enabling us to develop new technology to explore the ice and water environments of Earth and other planets. The long-term future applications of this project include subglacial explorations such as of Lake Vostok, Antarctica, and Europa, one of Jupiter's moons. At Europa, the ocean is thought to be beneath 10 to 40 kilometers of ice. The exploration will require descent through the ice with sufficient degree of mobility, acquisition of environmental and biochemical data in the ice, and observations in the subglacial ocean, all tasks of significant challenge. The Europa ocean may be as deep as 100 km and consequently at high pressure, about 1000 bars at the seafloor.

Fig. 8. Ice Borehole Probe Deployment Site.

Fig. 9. Ice Borehole Probe Deployment.

5. ACKNOWLEDGEMENTS

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7. BIOGRAPHIES

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